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Registration of Large Motion Blurred CMOS Images

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14. ABSTRACT
In the first part of this work, they addressed the coalesced effect of rolling shutter and motion blur that occurs frequently in moving CMOS cameras. First model was generated for a general image formation framework for a 3D scene following a layered approach in the presence of rolling shutter and motion blur. They then developed an algorithm which performs layered registration to detect changes. This algorithm includes an optimization problem that leverages the sparsity of the camera trajectory in the pose space and the sparsity of changes in the spatial domain. The second part of the work addressed the problem of registering images taken from global shutter and rolling shutter (RS) cameras and reveal the constraints on camera motion that admit registration, change detection, and rectification. Their analysis encompassed degradations arising from camera motion during exposure and differences in shutter mechanisms. They also investigated conditions under which camera motions causing distortions in reference and target image can be decoupled to yield the underlying latent image through RS rectification. In the final part of the work, a model for RS blind motion deblurring that mitigates many of the associated issues significantly was proposed. Comprehensive comparisons with state-of-the art methods reveal that their approach not only exhibits significant computational gains and unconstrained functionality but also leads to improved performance.

15. SUBJECT TERMS
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Abstract: Inevitable camera motion during exposure does not augur well for free-hand photography. Distortions introduced in images can be of different types and mainly depend on the structure of the scene, the nature of camera motion, and the shutter mechanism of the camera. Most present-day imaging devices are equipped with CMOS sensors and motion blur is a common artifact in handheld cameras. Because CMOS sensors mostly employ a rolling shutter (RS), the key challenges of registration, change detection, and motion deblurring problem take on new dimensions. Although few works have recently addressed these problems, they suffer from many constraints including high computational cost, need for precise sensor information, and inability to deal with wide-angle systems (which most cell-phone and drone cameras are) and irregular camera trajectory.

In the first part of this work, we attend to the coalesced effect of rolling shutter and motion blur that occurs frequently in moving CMOS cameras. We first model a general image formation framework for a 3D scene following a layered approach in the presence of rolling shutter and motion blur. We then develop an algorithm which performs layered registration to detect changes. This algorithm includes an optimization problem that leverages the sparsity of the camera trajectory in the pose space and the sparsity of changes in the spatial domain. In the second part of the work, we address the problem of registering images taken from global shutter and rolling shutter (RS) cameras and reveal the constraints on camera motion that admit registration, change detection, and rectification. Our analysis encompasses degradations arising from camera motion during exposure and differences in shutter mechanisms. We also investigate conditions under which camera motions causing distortions in reference and target image can be decoupled to yield the underlying latent image through RS rectification. In the final part of the work, we propose a model for RS blind motion deblurring that mitigates many of the associated issues significantly. Comprehensive comparisons with state-of-the art methods reveal that our approach not only exhibits significant computational gains and unconstrained functionality but also leads to improved performance.

The three publications related to these works contain detailed and complete descriptions of the proposed methodologies for registration, change detection, and deblurring in rolling-shutter images. We request the reader to refer to these papers which have been provided as attachments.

List of Publications and Significant Collaborations that resulted from this AOARD supported project:

a. **Papers published in peer-reviewed journals.**

1. Vijay Rengarajan, A.N. Rajagopalan, R. Aravind, and Guna Seetharaman,"Image Registration and Change Detection under Rolling Shutter Motion Blur**," IEEE Transactions on Pattern Analysis and Machine Intelligence (TPAMI),** November, 2016 doi: 10.1109/TPAMI.2016.2630687 *(TPAMI is flag ship journal of the IEEE Computer Society).*

b. **Papers published in peer-reviewed conference proceedings**:

1. Mahesh Mohan M R, A.N. Rajagopalan, and Guna Seetharaman, "Going Unconstrained with Rolling Shutter Deblurring," Accepted for publication at IEEE **International Conference on Computer Vision (ICCV),** Venice, Italy, October 2017. *(This is a very prestigious conference and has an acceptance rate of < 20%).*

c. **Manuscripts submitted but not yet published:**

1. Subeesh Vasu, A.N. Rajagopalan, and Guna Seetharaman, Camera Shutter-Independent Registration and Rectification, under review in the journal of **IEEE Transactions on Image Processing (TIP).** *(TIP is flagship journal of the IEEE Signal Processing Society).*

d. **List of interactions with industry or with Air Force Research Laboratory scientists or significant collaborations that resulted from this work.**

1. KLA Tencor, USA has sponsored a 75K US$ project for investigating noise and blur related issues in Scanning Electron Microscopy (SEM) images.
2. Google travel grant award to attend CVPR 2017 in Hawaii.
3. Microsoft travel grant award to attend ICCV 2017 in Venice.